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Wind wave measurements and modelling in a fetch-limited semi-enclosed lagoon

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ABSTRACT

The south-west reef lagoon of New Caledonia is a semi-enclosed basin where, on first approximation, dominating sea state component corresponds to locally generated wind waves. This study aims to evaluate the ability of the wave model WAVEWATCH III to simulate wind wave distribution in this particular fetch-limited context, with a given parameterisation. In order to evaluate the consistency of the simulation results, wave parameters were measured *in situ* by a wave and tide recorder (WTR9 Aanderaa) and by an acoustic Doppler velocimeter (ADV Sontek). This study underlines specific constrains for the deployment of instruments to assess the characteristic parameters of low amplitude and high frequency wind-waves. Special care was taken in the comparison step as, on one hand the wave model did not simulate the propagation of low-frequency oceanic waves inside the lagoon, and on the other hand the measured spectra bear an intrinsic limitation for high frequencies. The approximation of a sea state dominated by wind waves is verified on the study site. The accuracy of the simulation results is discussed with regards to the wind forcing applied to the model.

1. Introduction

In many coastal environments, waves have a major effect on re-suspension of benthic particles (Booth et al., 2000; Prandle et al., 2000). In the South-West Lagoon of New Caledonia (SLNC) re-suspension is the main origin of suspended particles, except during floods which are scarce and generally short (a few days per year at maximum) (Clavier et al., 1995). The SLNC constitutes a reference site for investigating the anthropogenic impacts on a coastal coral reef ecosystem. Since 1996, different parameters have been monitored in order to quantify the hydrodynamic functioning of the lagoon. Amongst others, physical parameters of the water column (Ouillon et al., 2005), turbidity by *in situ* measurements (Jouon et al., submitted for publication) and remote sensing (Ouillon et al., 2004), energy transfer across the barrier reef (Bonneton et al., 2007) have been extensively achieved. Finally, most of these parameters have been used for calibration and validation of numerical model simulations based on the coupling of a 3D hydrodynamic model with a fine particle transport model (Douillet, 1998; Douillet et al., 2001; Jouon et al., 2006). In the previous applications, the 3D hydrodynamic model took into account the tide and the wind but not yet the wave field.

So as to improve the sediment transport numerical model in such a shallow environment, it is necessary to simulate the wave field. The wave model will then be coupled to the hydro-sedimentary model (Grant and Madsen, 1979; Zhang and Li, 1997). Furthermore, a realistic wave model is required to simulate the extreme wind seas under cyclonic conditions.

In open lagoons, ocean waves and wind waves superimpose. In the SLNC, passes are relatively narrow compared to the enclosing reef extension (Fig. 1). Although ocean waves are strongly attenuated by wave breaking and friction over the enclosing reef flat (Bonneton et al., 2007), some of the oceanic waves enter the lagoon through the passes. The local wind intensity coupled to the dimensions of this semi-enclosed basin make it possible for wind to generate waves. A higher limit estimation of sea state characteristics can be assessed following the empirical SMB (Sverdrup, Munk, Bretschneider) method (Bretschneider, 1970). For a 10 m s^{-1} trade wind blowing over a 45 km fetch, during at least 5 h, the SMB method gives a significant wave height of 1.25 m and a 5 s peak spectral period in infinite depth.

In that context, this study was conducted to evaluate the ability of a wave model to simulate the wind wave field in a coastal semi-enclosed and fetch-limited environment and to quantify oceanic waves entering the domain. The work was conducted by application of the WAVEWATCH III model to the SLNC. The model results are compared with *in situ* measurements at different locations and under variable wind forcing conditions. In order to obtain measured data that are compatible with model outputs, the deployment of wave-meters required special care. On one hand, the implementation of WAVEWATCH used in this study did not simulate the transformation

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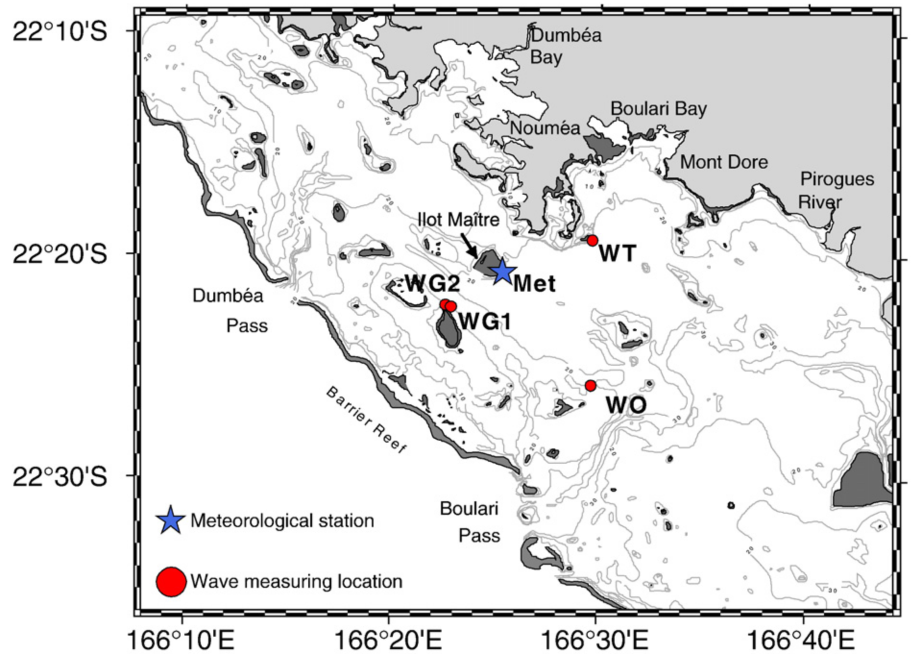

Fig. 1. SLNC bathymetry and location of wave measurement stations.

of oceanic waves, whose frequencies are low (<0.1 Hz). On the other hand, due to attenuation of high frequency components with depth, there is an intrinsic limitation of measured spectra at high frequencies. This last limitation is severe for wind waves in fetch-limited environments. This study illustrates how to select deployment locations for fetch limited wind waves measurements. It also underlines the importance of optimising the choice of the cut-off frequency in order to assess the most important part of the wind wave power spectrum. The comparison of simulated and measured wave spectra is performed over a windowed frequency spectrum. The results of the comparison may also constitute a guideline for the use of WAVEWATCH as a source of wave data for coastal engineering projects in fetch limited environments.

2. The study site

New Caledonia is a tropical island located in the Western Pacific, about 1500 km east of Australia. It is surrounded by a 22,200 km^2 lagoon. Noumea, the island's main city, is located on the south-west coast. The lagoon area which surrounds Noumea is called the SLNC. The SLNC whose average depth is 17.5 m houses many coral reef islands (Fig. 1). It is separated from the open ocean by a barrier reef incised by deep and narrow passes and distant to the coast from 5 km (northern limit) to 40 km (southern limit) (Fig. 1).

The local wind generates waves in the semi-enclosed lagoon, resulting from the wind action over a fetch of a few tens of kilometres long at maximum. Except for episodes of low wind intensity, the wind wave field is fetch limited. The mean wind waves periods are short (<5 s).

Statistic analysis of meteorological data (Douillet et al., 2001; Ouillon et al., 2005) brought out that the most frequent and long-lasting wind forcing was generated by South-Easterly trade wind regime. A second wind regime was also identified; it corresponds to more variable short lasting Westerly wind events.

3. Materials and methods

3.1. Field measurements

Two devices have been used in this study: a wave and tide recorder (WTR9, Aanderaa) and an acoustic Doppler velocimeter (ADVOcean, Sontek). For each measurement session, they were deployed simultaneously at the same location, mounted on a nonmagnetic structure that assures the sensors to be located 0.5 m over the seabed. Pressure measurements were achieved every 30 min.

3.2. Sampling strategy

Since the wave-induced pressure and velocity amplitude decrease exponentially with depth, when the signal to noise ration (SNR) becomes too weak, waves become undetectable at depths greater than a half wave length. According to this limitation, in this study, the maximum deployment depth was estimated under mean trade wind condition to about 5 m from the mean water level.

The short wave period context required taking special care in choosing the location and depth for the *in situ* measurements. The deployment conditions have to meet two opposite criteria; on one hand, the nearer the gauge to the mean water level, the higher the potential cut-off frequency; on the other hand, the probes have to be deployed close to sea-bed to avoid boat collisions during measurement episodes. For these reasons, shallow water areas were selected for deployment.

Due to topographic constrains, the wind intensity and direction vary from the outer lagoon to the head of bays. As the forcing wind in the model was measured in the outer part of the lagoon, we have selected shallow areas in the outer part of the lagoon. These specific locations correspond to the surroundings of coral islands within the lagoon.

Finally the measurement locations had to potentially correspond to areas where the wind waves reach maximum amplitude. This criterion was better met on the windward sides (defined for the main trade wind) of small reefs or small islands, within the main track of the lagoon where the wind waves have the greater fetch.

Three stations were monitored during this study (Fig. 1). WO station was the most southward site and received an oceanic influence through the Boulari pass. WG stations are located approximately at equal distance between the shore and the barrier reef. Two deployments took place nearly at the same location: WG1 from May 19 to June 1, 2006, and WG2 from June 8 to June 11, 2006. For technical reasons, the experiment at WG2 was shorter lived. WT was the closest station to the shore. Summary of the deployment sessions is given in Table 1.